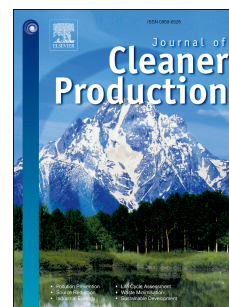


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Responsible mineral and energy futures: views at the nexus

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Abstract

Societal prosperity is underpinned by access to the increasingly interdependent resources of minerals and energy. In an era of mineral resource constraints and radical transition in the energy sector, this paper reviews the extent to which a long-term view of production and use is adopted in both fields. A long-term view including the mineral-energy nexus is deemed to be necessary (although not sufficient) for managing future resource constraints and energy transitions. Alarmingly, it identifies that the future of minerals resources and production is generally considered 5-10 years ahead rather than several decades or more as for energy. Additionally, the sectors are generally studied independently, rather than with a focus on the nexus. With these findings as evidence of an unaddressed problem, the paper then focusses on the current forces for change in the minerals industry: namely community drivers regarding social licence to operate, new technologies and consumer and government drivers on responsible minerals. As discussions of sustainable development become displaced by the emerging discourse of 'responsible' minerals, what is adopted and discarded? Whilst responsible minerals considers chain-of-custody, it does not adopt a long-term view and overlooks the mineral-energy nexus. Using three illustrative cases at the nexus of (i) rare earths-renewables, (ii) coal-steel and (iii) uranium nuclear we extend the theoretical discussion on 'responsible' with a range of contemporary examples from the perspectives of producing (Australia) and consuming countries (Japan, Switzerland) and propose a research agenda for an expanded notion of responsible minerals which recognises the complexity of the mineral-energy nexus and connects it to progressing sustainable futures.

Keywords: mineral-energy nexus; foresight; mining; environment; social licence; review; sustainability; supply chain

1 Introduction

The global production-consumption cycles of minerals and energy are inextricably connected.

Uranium is mined and used in nuclear power production; coal generates electricity used in mineral and metals production and is used as a reductant in blast furnace steel making; rare earth elements, – for example in wind turbine magnets – have enabled growth in renewable energy technologies. The energy intensity of primary mineral production is also forecast to increase (Norgate and Haque, 2010) as average mined ore grades decline (Prior et al., 2012) and there is significant potential for cleaner energy to be coupled to mineral production (McLellan et al., 2012; Memary et al., 2011).

This strong interrelationship between minerals and energy has been largely overlooked in discussions about mineral and energy futures, including in the emerging discourse of responsible minerals which has begun to supplant a focus on sustainability in the sector. The key aim of this paper is to examine the connections between these themes and foment a structured discussion on responsible mineral and energy futures. This is undertaken through critical analysis of futures practices in the two sectors and through specific examples of alternative contexts (producing and consuming countries) and important mineral-energy nexus cases.

As with public perspectives and policies in different countries, industry perspectives on sustainability, and their role in shaping the future, have differed and are not made explicit (Hilson and Murck, 2000). Historically, a failure to address this interrelationship in sustainability discussions about minerals and energy, citizens and industry, may have been a result of the fact that both sectors' sustainability concerns were previously associated with disparate issues. On the one hand, the minerals sector's sustainability discourses focussed on issues including resource depletion, mine site rehabilitation, air and water pollution and safety. On the other hand, the energy sustainability discussion has been dominated by concerns about energy security and peak oil, new technologies, and the link between fossil fuel consumption, global warming and climate change. The minerals energy nexus has not been a specific focus in sectoral sustainability debates.

On the ground, community and consumer perceptions about how minerals are obtained and used, have popularised the notions of the 'social license to operate' (Thomson and Boutilier, 2011) and social responsibility. In the context of mining, the social license to operate has become a community-driven, but non-formal extension of traditional mine licensing, where a mining project gains ongoing approval from local communities to continue activities (Prno and Scott Slocombe, 2012). The related concept of social responsibility suggests the needs for corporations to operate in a socially responsible manner – particularly with a view to future sustainability and intergenerational equity. In the last decade both notions have gained prominence in relation to the production of

minerals and energy – they hold relevance in the contexts of responsible production and ethical consumerism, yet social-licence is only beginning to adopt an explicit futures focus.

At a time when mineral and energy resource constraints may impact critical services on which society depends (Graedel et al., 2013), the notion of the social license to operate and rising awareness of responsible supply chains amongst both corporations (and consumers) emphasises the necessity to address these concerns at the minerals-energy nexus. However, understanding how responsible mineral and energy futures can offer pathways to sustainability – for communities and nations – requires assessment of the minerals-energy nexus at longer time scales and across global supply chains. Assessment and action should consider multiple perspectives at local and global levels, from the point of view of producers and consumers, and in relation to changing public and corporate perceptions of how society uses minerals and energy in daily life.

This paper concentrates on examining four aspects to advance the debate on minerals, energy and sustainable development, drawing on industry perspectives and those from producing and consuming countries. Firstly, how adequately is the minerals sector adopting a longer-term view, identified as a minimum necessary starting point to consider sustainable development? Secondly, in light of increasing interdependencies between minerals and energy, what are the characteristics of the mineral-energy nexus and risks of overlooking it? Thirdly, from an industry perspective, do these first two points feature within contemporary discussions on social licence and responsible minerals? Whilst discourses of responsible minerals include a focus on chain-of-custody, what aspects of sustainability are diminished; what additional elements could be proposed in an expanded notion of responsible minerals? Fourthly, how does the future-orientation and complexity at the mineral-energy nexus manifest from the perspective of producing and consuming countries for selected case studies? What can these example cases illustrate more generally about the dimensions of complexity which should be included in a research agenda for truly responsible mineral and energy futures that support sustainable development?

Australia, a significant minerals and energy producer, is contrasted with Japan and Switzerland as illustrative minerals consumers in Asia and Europe respectively. The countries use differing energy mixes, are characterised by differing mineral and energy management policies, and frame resource management responsibility differently, so present informative cases for comparison. The choice of countries was informed by the location of each the paper's authors and hence familiarity with the respective contexts and are used to illustrate the breadth of differences in the global energy and resources landscapes rather than being representative.

2 Mineral and energy futures: an overview

To date, there has been no review of the way in which mineral and energy futures are studied. To what extent do both sectors consider, make predictions about or seek to shape the future? Building on a review of mineral futures (Giurco et al., 2009), this section provides an overview of the 'future-in-view' for minerals and additionally in this paper, the energy sector.

We take the position that longer term foresight – rather than short-term forecasts – is a necessary pre-condition for sustainable and responsible mineral production (Prior et al., 2013a). As described by Riedy (2009), whilst there have been successful cases of science and technology foresight taking a long-term view which usefully progresses public policy and sustainability, these are often the exception rather than the rule. Consequently, careful consideration – by our present paper – of how mineral and energy futures are studied is a necessary first step to ensuring the discourse of responsible futures connects adequately across industry, policy makers and citizens to achieve impact. The point of departure and principal focus for our paper is on minerals; then energy and the minerals-energy nexus.

2.1 Mineral futures: production and demand

This section reviews how mineral futures are studied, with respect to different components of the production consumption chain, namely, resources, production, demand, recycling and so on. The intent is twofold – to determine what aspects of the future and time horizons are deemed important to study by governments, industry and researchers, and then, to review the tools and approaches used – do they for example acknowledge the mineral-energy nexus? The prevalence of futures-focussed work such as roadmaps, future scenarios and normative visions are also discussed and illustrative examples are summarised in Table 1.

Mineral futures generated by industry associations and governments generally adopt a narrow 'future-in-view'. (Note: in this study we have not examined the projections of individual operating companies, as much of their strategic work is commercial-in-confidence, as well as the complexity of obtaining a representative sample – however, this would be a useful focus of further research) Government geological associations tend to focus on periodically updated estimates of resources, although these are not forecast into the future. Forecasts for production and demand (by industry and government) are mostly over a 5-10 year time horizon (Giurco et al., 2009). Additionally, they are largely centred on supply-side forecasts of virgin ore production. The potential of recycled stocks of scrap material in meeting demand generally receives lesser attention, although (Hatayama et al., 2010) have a comprehensive model for steel.

Literature by academic researchers is beginning to draw attention to production over longer time horizons, often for single commodities using cumulative production trajectories based estimates of ultimately recoverable resources and population-led demand growth (e.g. coal (Mohr, 2010; Rutledge, 2011), copper (Northey et al., 2014), lithium (Mohr et al., 2012)). For steel which is discussed further as a case study later in this paper, the approaches to forecasting demand range from regression approaches (Crompton, 1999) and intensity of use models (Crompton, 2000) to dynamic material flow models in Japan broken down to the level of in-use stocks, obsolete stocks and overall stocks (Daigo et al., 2007).

The presence of valuable resources in obsolete stocks highlights the important potential of recycling (Graedel, 2011b; Reuter, 2005). Studies have looked at specific historical cases of recycling for steel (Yellishetty et al., 2011b) and rare earths (Binnemans et al., 2013) and some models based on end uses of metals and lifetime offer projections for scrap arisings (e.g. Melo (1999) for aluminium) and recycling rates (Michaelis and Jackson, 2000b) for steel) or environmental impact profiles associated with future rates of scrap recycling (Giurco and Petrie, 2007). Despite the increasing attention given to recycling by the academic community, it still remains an 'add-on' rather than core focus in the management of minerals and metals, with limited systematic future focus. This will need to become an integral part of future thinking in the minerals and metals sector when seeking closed loop systems of production and consumption (Giurco et al., 2014).

Roadmaps take an explicit future focus. For example, upstream roadmaps, such as *AMIRA's Copper Technology Roadmap* (AMIRA, 2004), *Canadian Aluminium Transformation Technology Roadmap* (Réseau Trans-Al Inc, 2007) and the *US Aluminum Industry Technology Roadmap* (Aluminum Association Inc., 2003) constitute a future-oriented analysis of sectoral trends and challenges focussed on alleviating production bottlenecks and providing strategic priorities for research and development and may consider end-of life issues and recycling. It is worth noting that how a roadmap exercise is conducted depends on the scope and sponsor.

Demand projections (more so than for production) are commonly forecast over the medium term (10-20 years), including in downstream industry roadmaps (e.g. *Building Construction Technology Roadmap* (Copper Development Centre Australia Limited, 2004)) and *Material Flow Analysis* (MFA) literature. In a recent review of MFA (Huang et al., 2012) its current functions include (i) building a systematic database or information pool (ii) determining critical links or pathways (iii) deriving meaningful and simple indicators and (iv) optimising material use and processing.

To support these functions, the Material Flow Analysis literature can either provide a static ‘snapshot’ of flows (and often stocks) through the life cycle of mining, processing, use, reuse for a given year (e.g. (Spatari et al. (2002); Spatari et al. (2003))) or dynamic modelling of historical or future flows (e.g. (McLaren et al. (2000); van Vuuren et al. (1999); Zeltner et al. (1999))). In developing dynamic models which are often undertaken for single commodities, Reuter (1998) highlights the importance of studying connected metal cycles, or the minerals-minerals nexus (as opposed to the minerals-energy nexus which is also important). Whilst this increases modelling complexity it is important, not only for primary production, for example where the possible banning of lead could have consequences for copper production (as lead is often a co-product or by-product) but also in recycling end of life goods (Reuter, 2013) – in addition the interdependencies at the minerals-energy nexus are increasingly relevant.

In some broad sustainability studies and modelling, mineral and energy resources are but one of several sectors considered. Here the nexus is captured, but the modelling is high level and the subtleties of the interconnections between minerals and energy are not explored. Integrating a quantitative analysis of population, non-renewable resources, food and industrial production and pollution, the World3 model in Limits to Growth explored quantitative scenarios (Meadows et al., 2004; Meadows et al., 1972) with the standard run being most similar to observed results over the past thirty years (Turner, 2008).

Four examples of broader, qualitatively described longer term futures in the minerals sectors are the plausible narratives of the Mining and Metals scenarios to 2030 by the World Economic Forum (World Economic Forum, 2010) and future visions of Vision 2040: Innovation for Mining and Minerals in Australia (Mason et al., 2011; Prior et al., 2013a), the remote and autonomous operations roundtable (McNab et al., 2013) and the Africa Mining Vision 2050 (African Union, 2009). These studies, like roadmaps, emphasise the imperative and the agency which stakeholders working together can exercise to adapt and also to shape the future. When developing longer term desirable futures, identifying worldviews can be helpful (Lederwasch et al., 2011) given that stakeholder views on conceptions of costs and benefits from minerals varies considerably (Cragg and Greenbaum, 2002).

Table 1: Contrasting examples of mineral futures literature

Classification	Description	Typical Sponsor	Typical Audience	Illustrative examples/References
Resource estimates	Estimates of 'economically available' resources/reserves or 'total' resources; often detailed by commodity or by country.	Governments	Industry	USGS (USGS, 2013); Geoscience Australia (Geoscience Australia, 2009) Researchers (Yellishetty et al., 2011a)
Production forecasts	Often quarterly or annual forecasts over 3-5 (or even 10) years, usually from government or industry forecasters by commodity or by country. Some research scholars model longer time horizons (see also MFA literature)	Government Researchers	Industry; Government – treasury and sector policy Industry, government, researchers	BREE (BREE, 2013) Lithium (Mohr et al., 2012) Copper (Northey et al., 2014; Zeltner et al., 1999) Steel (Daigo et al., 2007)
Upstream roadmaps	Often for a single commodity (e.g. copper, steel, aluminium) looking at technology trends, drivers and sectoral innovation in production	Industry	Industry and government policy	AMIRA Copper Technology Roadmap (AMIRA, 2004) AMIRA Alumina Technology Roadmap (Amira International, 2001)
Demand forecasts	Projections of demand (either economic growth by country) or tonnes by commodity	Industry Researchers / Think tanks	Investors Investors, industry, society, government, research	Global Commodity Demand Scenarios (Access Economics, 2008) (Meadows et al., 1972) (Crompton, 1999, 2000)
Downstream roadmaps	Downstream roadmaps direct attention toward the final end uses of minerals and metals and how these are changing and evolving	Industry and government	Industry and government, supply chain partners	Automotive Steel Roadmap (American Iron and Steel Institute, 2006) Copper Applications Technology Roadmap (The International Copper Association, 2007) Building Construction Technology Roadmap (Copper Development Centre Australia Limited, 2004)
Recycling rates and urban stocks	Publication of recycling rates may or may not in addition reflect urban stocks of metals	UN Industry associations Researchers	Recycling industry	International resource panel (Graedel, 2010; Graedel et al., 2011) USGS (USGS, 2011)
Material Flow Analysis	Material flow analyses are published more by academic researchers than government agencies (especially Europe, Japan)	Research	Research and government policy	(Giurco, 2005; Hatayama et al., 2010; Reuter, 2005; Spatari et al., 2002; Zeltner et al., 1999).
Quantitative (forecasting)	Quantitative scenarios forecast material use	Industry associations,	Industry and government	Access Economics (Access Economics, 2008); UNEP

scenarios	from the present, along a future trajectory under 'business as usual' and other scenarios of low/high growth (or other policy differences)	UN		(UNEP, 2007)
Scenarios: Plausible narratives	Another approach to scenarios is similar to the classic use of the scenarios as popularized by 'Shell' for considering uncertainty in future, distinct worlds, described qualitatively. Strategies can be tested for robustness under each scenario.	World Economic Forum	Industry and Government	World Economic Forum (World Economic Forum, 2010)
Backcasting (expert) scenarios	As opposed to forecasting (where might we go from here/today) – backcasting asks 'where do we want to be?' and 'how do we get there?' informed by experts under a range of scenarios			–
Vision (deliberative)	A vision (or preferred future scenario) could also be developed by experts, but that described here involves greater stakeholder deliberation.	Research, Government	Civil society, Government, Industry	Vision 2040 (Mason et al., 2011; Prior et al., 2013a) Autonomous and remote operations roundtable (McNab et al., 2013) Africa Mining Vision (African Union, 2009)

Responsible mineral futures will involve a dual focus on primary production and an increased focus on recycling. A key shortcoming of the status quo evidenced in Table 1, is that unlike resource estimates from geological deposits where funded government departments provide annual estimates of resources, there is a paucity of standardised and regularly collected information regarding secondary stocks. Where it occurs, it is either by industry or academic researchers, where the continuity of data collection can be subject to securing ongoing funding for such tasks and thus cannot be relied upon. Furthermore, long term production forecasts are not undertaken by government or international agencies (in the way that energy production forecasts are), but for selected commodities by researchers.

Whilst industry sponsored research (Access Economics, 2008) considers quantitative future scenarios, exploration of publicly available qualitative scenarios with plausible narratives reflecting deeper changes in the socio-political landscape are not sponsored by individual mining companies

(unlike for example Shell who have a forty year history of scenario planning). Indeed these broader scenarios and visions illustrated in Table 1 are developed by the World Economic Forum, the multi-stakeholder African Union and academic researchers. The industry and indeed government view on mineral and resource futures, is currently too short-sighted to underpin the sustainable use of resources and furthermore, needs to better recognise the interdependence at the minerals-energy nexus.

2.2 Energy futures: a longer view

By contrast, several examples of energy futures have adopted a time horizon of 2030 (e.g. BP Energy Outlook; World Energy Outlook) based on quantitative forecasts (BP, 2011; IEA, 2013). In addition there is also more literature on plausible future scenario narratives such as those developed by Shell (Shell, 2013) backcasting of energy futures (Ashina et al., 2012; Giurco et al., 2011; Robinson, 1982) or more radically changed cleaner energy futures, such as those developed for Australia (Beyond Zero Emissions, 2010; CSIRO, 2006). The centrality of secure energy supplies to national economic prosperity and social wellbeing could be part of the reason for this longer term focus.

Considering a country that is exceptionally resource-constrained (such as Japan), energy policy regularly forecasts out to 20 years in the future and perennially highlights energy security as a key element (Vivoda, 2012). Given the additional constraints of concerns over energy safety and the desire to reduce greenhouse gas emissions, such forecasts use complex models incorporating multiple social, environmental and technical constraints (see for example Zhang et al. (2012b)). These models consider scenarios out as far as 2100, although it is difficult to consider the accuracy of such forecasts (Zhang et al., 2012a).

The ability to apply such models is perhaps one advantage of energy futures, in that the technologies are relatively universal (coal-fired power stations are largely similar), with minor parameter changes allowing large scale modelling. This may be contrasted with minerals, in which each specific ore can be unique, especially for rare earths. In contrast to minerals resources estimates focusing on supply, the prediction and planning of energy is highly focused on demand. Demand predictions are made based on historical load patterns, and the influence of technology can be incorporated, but the element of market penetration and societal take-up of technology across a diverse end-user market is cause for great uncertainty in estimates.

An illustrative example of energy futures domains of publications are shown in Table 2.

Table 2: Contrasting examples of energy futures literature

Classification	Description	Typical sponsor	Typical audience	Illustrative Examples/References
Resource estimates	Estimates of coal, oil, gas, uranium.	Government	Government and Industry	USGS(USGS, 2013); Geoscience Australia (Geoscience Australia, 2009)
Production forecasts	For energy this can be decades ahead, rather than just 3-5 years for minerals	Industry or Association	Government, Industry, Research, NGOs, Citizens	BP Energy Outlook (BP, 2011); International Energy Agency (IEA, 2013)
Upstream roadmaps	Regarding technologies relating to energy production (e.g. CCS; wind, thorium production)	IEA; Researchers	Energy sector, policy	CCS (IEA, 2009a) Wind energy (IEA, 2009c) Thorium (Furukawa et al., 2008)
Demand forecasts	Demand for energy consumption (can be published with energy production forecasts)	Industry or Association	Government, Industry, Research, NGOs, Citizens	(IEA, 2013; Zhang et al., 2012b)
Downstream roadmaps	Roadmaps relating to energy use (e.g. electric vehicles, storage technologies)	Research, Association	Industry, Policy	(IEA, 2009b)
Quantitative (forecasting) scenarios	Includes integrated resource planning	Government	Government and Industry	(D'Sa, 2005; Department of Energy (South Africa), 2011; Graham, 2006)
Scenarios	Plausible narratives	Research / World Council for Energy	Policy: industry and government	(Schiffer, 2008)
Backcasting (expert) scenarios	Desired future scenarios	Researchers	Government and industry	(Giurco et al., 2011; Gomi et al., 2011; Robinson, 1982)
Vision (deliberative)	Vision for energy futures within the future (sustainable)	NGO	Government and industry	(Beyond Zero Emissions, 2010)

2.3 Key differences between minerals and energy

Examining the approaches to futures in the minerals and energy sectors, important differences appear: (a) time horizon for forecasts; (b) demand considerations; (c) ability to develop normative futures; and, (d) level of consideration of social impacts of new technology deployment.

Regarding the first of these, in general, governments, large energy-based companies and international industry bodies such as the International Energy Agency or the International Atomic Energy Agency, consider the stable supply of energy vital to societal, national and corporate interest. They therefore take a longer term view of futures of energy. In addition, with the implications of climate change policy and the cost and roll-out of conventional as well as new energy technology, predictions of resources and performance at both the supply and demand end of the supply chain are integral to identifying appropriate investment priorities.

Regarding demand considerations, the energy industry must consider alternative demand across a variety of other industry sectors, as well as commercial and residential consumers. Futures need to take account of the type of energy to be consumed, the technologies expected to be implemented and the rates of change of demographics and political policy as well as markets. Moreover, the variety of consumers require alternative pricing strategies, thus the demand considerations are generally more sophisticated in energy futures.

Despite the level of sophistication and variety in demand considerations, the energy industry is also able to develop more normative futures, as the technology is largely globally applicable and developmental characteristics can be readily traced across alternative economies. By comparison, the minerals industry has a wide variety of supply-side variation with regards to ore type and grade, but the demand side – particularly the final end usage of minerals is relatively difficult to predict given the development of technology and alternative consumer products. Moreover, individual national reserves of minerals are widely varied, as are the industries that utilise them, making normative futures challenging at the national scale.

Finally, the level of consideration of impacts of new technologies is also more advanced within the energy industry – for a number of reasons. Although there are examples within the minerals industry – for example with the toxic effects of minerals causing their phase out in applications such as lead paint, cadmium and asbestos, or the impacts of major operations in the supply chain – the energy industry considers the roll-out of technologies such as alternative fuel vehicles and smart grids, costly technologies for carbon mitigation, or behavioural change for efficiency improvements, which have wide-ranging social implications.

Further characteristics of the minerals and energy industries which may influence the industries' respective perspectives on sustainable futures and the complexity of the mineral-energy nexus are given in Table 3.

Table 3: Comparison of key elements in minerals and energy industry highlighting the complexity of the mineral-energy nexus

	Minerals Industry	Energy Industry
Industry structure	Relatively linear – main consumer base at the manufacturing level; vertically integrated companies (mining, production, manufacturing) are less common – although some are emerging in areas where security of supply is concern (e.g. rare earths or integrated lithium mining through to battery manufacturing)	Variety of supply chain structures – domestic producers in energy resource-rich countries have short, linear supply chain; Producers reliant on global supply chain have highly interconnected / branched supply chain;
	Historically, retail consumers were unlikely to have awareness of the mineral content or origin of products; this is changing and awareness is growing (e.g. Fairmined gold)	Many direct consumers – small to large scale; customers can elect to buy ‘wind power’ or ‘green energy’ from retailers.
	Many large global-scale companies; minority of production comes from state owned enterprises; some commodities supplied by artisanal or small scale miners	Few global-scale companies (except in fuel supply); majority of production comes from state owned enterprises; Electricity companies typically domestic;
	Supply and demand interaction drives production outlook	Demand drives production outlook
Supply	Only large scale producers can also be consumers;	Potential for consumers at all scales to also be suppliers;
	Global market is the norm;	Domestic market is the norm; (fuel is an exception; as are interlinked grids in Europe and North America)
	Cut in supply has delayed impacts	Cut in supply has immediate impacts
	Reserve-driven outlook	Technology-driven outlook
Demand	Mostly large scale – until integrated in products;	Mix of fewer high consumers (heavy industry) and many smaller consumers (households and small business)
	Forecast on a yearly or quarterly basis	Forecast on a basis of seconds through to decades
	Influences primary commodity prices	Influenced by commodity prices such as coal, uranium as well as policy
	Economy-driven outlook	Strong technology and policy influence in outlook
Sustainability perspective	Minimise water and energy use and toxic discharges; keep local community happy; not strong closed loop focus	Coal part of problem, solar, wind, geothermal and nuclear can be part of solution
Responsibility perspective	“Responsible” minerals taking over as term of choice in place of stewardship, sustainability to show acceptable social and environmental practices along supply chain	Responsible energy (e.g. in EU) linked to that which is acceptable for climate; in Alberta relates to legislation covering coal and oil sands.
Social licence (to operate)	Raised most commonly at the scale of the extraction site, securing and maintaining social licence is acknowledged as key to the future of the industry	Raised commonly at scale of extraction site (e.g. local opposition to wind-farms), but also sector-wide (e.g. the nuclear industry losing its licence to operate after Fukushima, not only in Japan, but also Germany and Switzerland; or public opposition to hydraulic fracturing).
CSR considerations	Economic potential of sector but not ‘public requirement’ sentiment in most cases, rather social licence to operate is important.	Electricity considered a “public good” or “essential service”
Argument for	Ongoing ability to extract – profitability, jobs	Use of current technology - Economics and profit

status quo by sector		
Main dimensions of minerals-energy nexus acknowledged	Use of minerals in clean energy technologies (e.g. lithium) Embodied energy of steel, aluminium etc. in contrasting greener building materials	Critical minerals required for wind turbines, solar cells

2.4 Importance of the minerals-energy nexus view

Like many of the issues associated with sustainability and the interdependent nature of complex systems, energy and minerals converge and overlap with bidirectional influences. Studies of life cycle impacts and the supply chain embodied energy inputs to minerals are one field where this connection has been considered for some time. Such studies are represented in both static comparisons of alternative materials (for example in the energy usage for steel versus aluminium (Zabalza Bribián et al., 2011)) and in time-series studies comparing past energy intensity and estimating future potential for energy intensity shift due to declining ore grades or shifts in ore and process type (Memary et al., 2011; Mudd, 2007). The importance of the cost of energy is also well recognised, as one of the key elements of competitiveness that has shifted the location of various minerals operations in order to take advantage of lower energy prices.

With regards to the inverse situation, minerals inputs to energy have only been recognised as significant when prices and scarcity have been apparent or imminent – such as the “critical metals” including rare earths such as neodymium utilised in permanent magnets for generators and motors (Graedel, 2011a; Nansai et al., 2014). In this regard, the convergence of minerals futures in the form of supply has been integrated with energy futures looking at demand from new energy technologies. However, even conventional inputs such as steel are important for the development of energy technologies like shale gas, which in the USA has each directional rig consuming up to 4,200 tonnes of steel per year (Crawford, 2012). Simultaneously, it is also important to consider interconnected minerals supply chains, for example many of the critical metals are by-products of the production of other major minerals. Moreover, polymetallic mines are producing a significant proportion of some minerals. These interconnections have implications for the allocation of embodied energy and for the responsible supply of minerals in the future – overlooking the nexus risks ignoring possible supply constraints or changes to demand or social licence from one sector to the other.

This section makes the following propositions: (i) a long-term-view is necessary (but not sufficient) condition for sustainable resource and energy management (ii) the interdependency of the mineral and energy sectors makes it increasingly important to consider the mineral-energy nexus explicitly in future planning (iii) the future focus currently adopted in the minerals sector of less than a decade is too short and should be extended at least to multiple decades to a century as for energy.

The next section will examine how the current discourses of social licence, sustainability and the increasingly preferred term “responsible” intersect with the aforementioned propositions to identify limitations and potential additions relevant for an expanded notion of ‘responsible’.

3 Conceptualising ‘social licence’ and ‘responsible’ in the energy and mineral sectors

The previous section has discussed the way both mineral and energy sectors look at the future. Future trajectories for the mineral and energy sectors are also influenced by new technologies and the scale at which each frames and discusses ‘social licence’ and more recently “responsibility”, which itself has evolved from discussions of sustainability. The aim of this section is to review whether community and government planning and contemporary industry discourses take sufficient consideration of a long-term-future focus and the mineral-energy nexus.

3.1 Social licence to operate

Social Licence to Operate is a term that originated in the mining industry, which refers to an intangible and unwritten, tacit, social contract with society, or a social group, that enables an activity (in this case a mining or energy development) to enter a community, start, and continue operations (Lacey and Lamont, 2013; Moffat and Zhang, 2014; Prno and Scott Slocombe, 2012; Thomson and Boutilier, 2011). The term recognises the power that local communities and civil society more generally can have on the success, or otherwise, of mining and energy developments. Companies have frequently experienced significant delays, costs, and even project abandonment or withdrawal of regulatory approval, in circumstances where public support for development has been absent or withdrawn (Franks et al., 2014). Mineral developments are particularly vulnerable to shifting public sentiment because ore reserves are anchored to specific geographic locations and once implemented technology is difficult and costly to retrofit (Franks et al., 2014).

Social licence is critical to mineral and energy futures, however, considerations at the nexus are under-represented. For example, the social licence issues surrounding the development of the Lynas Advanced Materials Plant (LAMP) in Kuantan, Malaysia (Ali, 2014) notwithstanding the legitimate concerns of the local community, constraining production in rare earths by delaying the project, could also affect the future development of clean energy technologies.

Public opposition can manifest at different geographic scales and locations (from site level opposition through to widespread societal rejection of a particular technology, commodity or industry, including by investors). While the production of minerals has frequently been the subject of site-level opposition to development, the energy sector has experienced a greater degree of public opposition to particular commodities or technologies (see Table 2). Examples include opposition to, uranium, coal, nuclear power, or even the specific drilling techniques used in unconventional gas extraction (hydraulic fracturing).

The potential impact of social licence to operate on the supply of minerals and energy has increasingly motivated better consideration of public support and perspectives in futures studies, as discussed below. The minerals industry sees maintaining social licence as essential to its future and attempts to connect social licence to technological and regional futures are discussed below.

3.1.1 Technology futures and social license in design

Within both mineral and energy futures, new technologies play an important role in future supply and demand and technology innovation is progressing in both sectors. Table 4 lists a selection of emerging mineral technologies to provide an indication of some of the current areas in which technological development is focussed. Technology innovation has varied implications depending on geopolitical factors, with technologies aimed at increasing the resource base and enabling further extraction more relevant to producing countries, and technologies designed to facilitate the recovery of resources from wastes, centred more on consuming countries. The importance of the mineral-energy nexus and social licence for both differs.

Table 4: Overview of emerging technologies for minerals extraction

Emerging technology focus	Description	Examples/References
Identification or resource base	Technology to better locate and map resources	3D mapping (CSIRO, 2008)
New extraction methods	New development and application of methods to access existing or more complex resources	Oil shale & shale gas (Jiang et al., 2007)
		Phytomining (Anderson et al., 1999)
		Bio-leaching (Bosecker, 1997)
		In-situ leaching (Mudd, 2001)
Access remote/difficult resources	Technology to improve access of deep terrestrial or ocean resources	Super block-caving (Chitombo, 2010)
		Deep sea mining (Halfar and Fujita, 2002)
Recovery of resources from end of life goods	Technology for reprocessing and recycling	Batteries (Bernardes et al., 2004)
		Printed circuits (Huang et al., 2009)
		Automobiles (Reuter, 2005)
Increase productivity	Technology to increase the throughput, cost structure or safety of extraction	Automation and remote tele-operation (McNab et al., 2013)

New minerals technologies range from in-situ or deep sea mining to phytomining; regarding energy they range from next generation solar or nuclear technology, to wind, geothermal and carbon

capture and storage. When considering technology futures, much of the focus resides on 'getting the technology working' from a technical point of view. Recently a number of futures studies have given consideration to the social dimensions of technology and its acceptability upon deployment (Franks and Cohen, 2012; McNab et al., 2013; Weldegiorgis and Franks, 2013). Franks and Cohen (2012) developed a technology assessment process to incorporate multiple stakeholder perspectives into technology design. This process of 'social licence in design' (Franks and Cohen, 2012) has been used to investigate the technologies ranging from the use of biomass in steel-making (Weldegiorgis and Franks, 2013) to mine-site automation and remote tele-operations (Franks and Cohen, 2012; Giurco et al., 2012). These studies have allowed technology developers to weigh up different technology configurations and append social metrics to traditional economic and technical measures. For example, Weldegiorgis and Franks (2013) were able to demonstrate that the specific technology configuration of the biomass alternatives analysed had a large impact on the societal outcomes and the potential level of public support for the technology. The next step as part of responsible mineral development, would be to extend this thinking across the minerals-energy nexus.

In the energy sector, technology is the most important consideration in regards to the mapping of potential futures – whether solar energy and nuclear fuel or coal-fired power stations. However, technology is closely linked with energy security, economics and the reduction of GHG emissions. The nuclear accident at Fukushima in 2011 enhanced the Japanese public's concerns over nuclear energy, leading the government at the time to pledge a withdrawal from nuclear power by the 2030's (National Policy Unit, 2012). Despite this change, the technology focus – on energy efficiency or on substitute technology – is still the dominant policy consideration (McLellan et al., 2013). Energy efficiency has been embraced by governments, households and industry in order to alleviate any shortage of electricity (IEEJ, 2011) – however, the lack of nuclear energy has impacted the country's GHG emissions and the economy (Vivoda, 2012). The greenhouse emissions of burning fossil fuels are also increasing their risk profile and costs.

Highlighting the importance of stakeholder input in energy technology futures is the fact that many new energy generating technologies are distributed (often at the household scale – for example rooftop PV). On the demand side, new technologies may be highly intrusive in what may be considered the "personal" domain – for example "smart" control systems that could allow control of energy-intensive activities within the home by energy companies, or the use of electric vehicles as substitute storage and supply for the grid (Zhang et al., 2012c).

3.2 Future planning: community and government

3.2.1 Regional and community futures

Whatever the technology, it will be deployed and operated in a physical community. In an analysis of the way in which regional and community futures were studied and understood in resource rich regions in Australia, it was found that planning needs to (i) extend beyond economics to social and environmental issues and (ii) extend beyond the life of the mine to post-mining transitions and rehabilitation of land (Giurco et al., 2009; Giurco et al., 2012). Governments were identified as having a role in smoothing the impacts of boom-bust cycles, yet are often struggling to keep pace with current industry development, let alone plan with the community for futures beyond mining. In the mining industry community development activities have largely been approached through the lens of corporate social responsibility and insufficiently linked to government and regional planning processes or long-term community development needs. Responsible futures for communities and indeed nations, also requires using the proceeds of mining to underpin prosperous futures beyond mining.

3.2.2 National resource and energy futures

The focus which governments put on developing national resource and energy strategies is highly variable. To illustrate this point Australia does not have a national minerals strategy, with efforts being coordinated by individual states – this was identified as significant gap in *Vision 2040: Mining Minerals and Innovation* (Mason et al., 2011). The state of Queensland (Australia) recently began developing a long-term thirty-year strategy for resources and energy development and management called ResourcesQ, drawing on elements identified in Vision 2040. By contrast, national energy policy is more closely considered, with an updated national energy white paper currently being developed in Australia.

In Switzerland too, energy has greater long term focus at the national level, through the *Energy Strategy 2050* (Swiss Federal Office of Energy, 2014). This new policy extends the existing policy by introducing the concepts of the '2000 watt society' or 'one tonne of CO₂ per capita society' (Swiss Federal Council, 2011). These initiatives aim to draw down Swiss society's energy consumption through paradigm changes in both energy policy and in society's energy use. Given that Swiss-based firms control 15-25% of the global trade in commodities, consideration is given to the challenges of addressing transparency and accountability in the commodities sector, including via the UN Global Compact, and Extractive Industries Transparency Initiative.

Japan takes the most integrated minerals-energy view, given that it depends on imports from abroad for most of its energy resources and mineral resources. Laws demand that a sound material-cycle society that promotes suppression of consumption of natural resources and reduction of environmental loads should be established through promotion of policies to advance the Reduction, Reuse, and Recycling (3R) of products and adequate waste treatment. Aiming at such conversion to a sound material-cycle society, The Basic Act on Establishing a Sound Material-Cycle Society was enacted in 2001, the first Fundamental Plan for Establishing a Sound Material-Cycle Society was formulated in 2003 for its deliberate execution and the plan has been reviewed every five years since then. The third plan approved in the cabinet meeting in 2013 assigns importance to the promotion of activities to Reduce and Reuse goods and to the collection of valuable metals such as rare metals from discarded compact appliances such as cellular phones and music players and the enhancement of recycling. Japan has also been making international efforts in support of the formulation of a cyclical society on a global scale through deployment abroad of waste and recycling industries now operating in Japan. An outstanding feature of this fundamental plan is that numerical targets have been set for three items (resource productivity, ratio of material cyclic-use, final disposal) that emphasize nationwide material flows (Moriguchi, 2007). Targets to be accomplished by 2021 are 46 (10,000 yen/t), 17% and 17 Mt, respectively. This integrated view adopted by the government is a useful basis on which to plan mineral and energy futures, however, such integrated views are not common to most 'responsible' minerals initiatives due to a focus on conventional resources only.

3.3 Industry framing of 'responsible' minerals and energy

3.3.1 Background to the use of the term 'responsible'

Various terms are used in the minerals and energy sectors used to convey environmentally and socially acceptable practices, in addition to social licence to operate, including "sustainable", and "responsible". A simple google search shows that "responsible mining" is now about as common as "sustainable mining" and indeed "responsible energy".

In the minerals sector, the term 'responsible minerals' has begun to take hold and whilst still ambiguously defined, is less environmentally focussed than 'sustainable minerals'. It certainly does not aspire to a strong sustainability position of exploring the role of minerals in a sustainable world, but rather of 'doing the right thing' along the supply chain, including regarding social practices. In this way it has a broader supply chain perspective than 'social licence to operate' discussed in the

previous section, which is generally discussed with respect to a particular site or technology, yet it still does not adequately address unsustainable rates of final material consumption. Its rise may be linked to fatigue with the term ‘sustainable’ and in response to ‘sustainable’ being seen as too broadly defined or green-wash in the sector.

A recent paper using the term “responsible supply chain management” (Hoejmose et al.) say responsible supply chain management (RSCM) can be pursued to:

- 1) protect reputation or
- 2) enhance reputation to get market share.

Whereas ‘sustainable’ may have been adopted by companies to protect or enhance reputation at sites of operation in relation to securing social licence, “responsible supply chain management” has by definition an explicit focus on the supply chain and its use in this way (outside of the minerals sector) also comes to convey a focus on ‘supply chain’ when using the term ‘responsible minerals’ and is now discussed further.

3.3.2 Sustainable minerals

In exploring the use of ‘responsible’ in the minerals industry to reflect new and better ways of doing things, in place of sustainable, it is interesting to see what aspects of ‘sustainable’ are no longer considered, either implicitly or explicitly. ‘Sustainable / sustainability’ is now a focus of sustainability reporting for companies (e.g. BHP Billiton (2013)) whilst at the sectoral level it has become connected with mining as a sector having the potential to be a contributor to sustainable development (ICMM, 2012; Lambert et al., 2013).

Corporate social responsibility (CSR) trends over the last twenty years have seen increased disclosure of comprehensive environmental, social and health impact reports, and further standardisation of reporting guidelines (Mudd 2010). There has been a growing demand for increased reporting (e.g. Global Reporting Initiative) at both corporate and site levels, and for the use of sustainability indicators that can be verified by third parties (Jenkins & Yakovlova 2006; Sampat & Cardiff 2009). Reporting information transparently to local communities is also an important part of maintaining social licence at sites and for companies as a whole.

Cowell (2000) identifies a dichotomy between the perceptions and actions of how sustainability is adopted in theory and practice for the extractive industries noting differences with respect to: relative emphasis on social, economic, environmental; treatment of uncertainty (degree of embrace of precautionary principle); scale of focus; and time horizon. In a comparison of sustainability frameworks used in the mining industry (Fonseca et al., 2013) notes that they downplay the problem

of (proven) mineral reserves at the global level and are often retrospective rather than prospective. This too is largely the case for 'responsible minerals'.

Looking to a sector-wide perspective, Building on the Mining, Minerals and Sustainable Development (MMSD) project, the International Council on Mining and Metals (ICMM) was created and established key principles of sustainable development to which the global mining industry would aspire. It has now taken the discussion of sustainability to be concerned with the contribution which vibrant mining industries (particularly in developing economies) can make to what is referred to as 'sustainable development' for the country. ICMM has also introduced a material stewardship toolkit focussing on taking a systems perspective, building relationship, understanding materials and sharing data (ICMM, 2013).

3.3.3 Responsible mining and minerals

By contrast, an ICMM websearch returns results on "responsible mining in conflict-affected areas". These chain-of-custody and 'traceability' implications of not sourcing material from conflict affected areas introduces an explicit 'supply chain' dimension to the use of the term responsible mining and minerals. The specific manifestation of 'responsible minerals' regards 'chain of custody' approaches to supply chain performance as shown in Table 5.

With respect to the corporate motivations identified by (Hoejmose et al., 2013) for engaging in responsible practices of (i) protecting reputation and (ii) enhancing market share, both are relevant for responsible steel and aluminium stewardship which are industry led, but also for responsible jewellery and to some extent the initiative for responsible mining. However, those led by governments (Dodd-Frank) and communities.NGOs (No dirty gold and also Fairmined/FairTrade) are driven by avoiding poor social practices in the supply chain.

Table 5: responsible supply chain initiatives

Scheme	Origin	Focus	Description
Dodd-Frank Act (Regulation)	USA Government	Companies	Regulation regarding conflict minerals from Democratic Republic of Congo (cassiterite, wolframite, coltan, and gold). Companies subject to the US Securities and Exchange Commission are required to disclose whether above minerals used in their products originate from DRC or surrounding countries
Fairmined/ Fairtrade	Alliance for Responsible Mining / Fairtrade International	Supporting Artisanal and small scale miners	Voluntary certification of small scale miners. Final sellers of gold receive Fairtrade symbol. Currently being phased out in favour of more flexible model.

No dirty gold	USA	Community awareness to pressure US retailers (e.g. Macy's) to avoid dirty gold.	Public awareness website.
Responsible Steel	Australia	All companies in supply chain	<p>The Steel Stewardship Forum brings together the steel product life cycle – from mining through to steel manufacturing, processing, product fabrication, use and re-use, and recycling – in the shared responsibility of working together to minimising the impact on society and the environment.</p> <p>It aims to be presented at the APEC Mining Ministers Forum as a 'best practice' model for the region.</p>
Responsible Jewellery Council	International	Companies along jewellery supply chain (ISEAL member; also has chain-of-custody standards)	<p>"The Responsible Jewellery Council is a not-for-profit, standards setting and certification organisation. It has more than 440 Member companies that span the jewellery supply chain from mine to retail" "The Code of Practices addresses human rights, labour rights, environmental impact, mining practices, product disclosure and many more important topics in the jewellery supply chain."</p>
Initiative for Responsible Mining Assurance	International	Focus on medium to large scale mines	<p>"IRMA is establishing best practice standards that improve the environmental and social performance of mining operations, as well as a system to independently verify compliance with those standards."</p>
Aluminium Stewardship	Run by International Union for the Conservation of Nature (IUCN)	Has a focus on bauxite mining and smelting industry (more than consumers)	<p>"The Aluminium Stewardship Initiative (ASI) was initiated in 2012 to foster greater sustainability and transparency throughout our industry. Spearheaded by several industry players, the ASI is a non-profit initiative that seeks to mobilise a broad base of stakeholders to establish and promote responsible leading practices, across the aluminium value chain, in business ethics; environmental performance; and social performance."</p>

The development of responsible 'supply chain' standards takes the focus of sustainability within the minerals sector from site-based performance (where some companies considered lowering water and energy use per tonne of product 'sustainable' even if they double their output) to supply chain

performance or ‘social-licence to market’ (Benn et al., 2014). It has also broadened the notion of ‘sustainable’ from largely environmental performance and compliance to also include social performance along the supply chain. However, what is still not widely acknowledged is a long-term future focus, including the role that metals play in the economy and what levels of production and consumption are appropriate and sustainable (Michaelis and Jackson, 2000a) as well as the complexity of the system in which mineral production consumption occurs (Cooper and Giurco, 2011), including the acknowledgement of the mineral-energy nexus.

3.3.4 A brief note on responsible energy definitions

Being a lesser focus within this paper than minerals, responsible energy is not reviewed comprehensively. Worth noting is that it is used with contrasting meanings, for example, in Europe it is linked with energy solutions that protect the environment from greenhouse gas emissions (see blog by GE and the Assembly of European Regions <http://refer.blogactiv.eu/about/>). While in Alberta, Canada, the “Responsible Energy Development Act” is legislation covering the ‘environmentally responsible’ extraction of coal, oil, oil sands and gas (Province of Alberta, 2012).

3.4 Extending the emerging notion of ‘responsible’

The emergent notion of ‘responsible’ has several shortcomings which need to be addressed if it is to make a useful contribution to mineral and energy futures.

Within the minerals sector, responsible has become at times a replacement-lite for sustainability, with a greater focus on supply-chain connections and provenance, but without a focus on strong (or even weak) sustainability. Reducing water and energy per unit of product are highly valued, overlooking total throughput (total water and energy) and availability of stocks in terrestrial and urban landscapes. The rebound effect is also not considered (Giurco et al., 2014).

Furthermore, new questions arise when considering the minerals-energy nexus in an integrated way. For example as posed by Giurco et al. (2014) is “responsibly sourced” represented more by:

- (i) *a mine where the workers are well paid and which utilises clean energy and processing practices, or;*
- (ii) *whether the metal comes from recycled post-consumer scrap (or even home scrap/recycled production waste)?*

Design for recycling will necessarily become more important (Gaustad et al., 2010) as there is a live trade-off between using more metals in complex product alloys which may be more efficient during use but are more difficult to recycle and simpler alloys which are more readily recycled. The

principles of industrial ecology (Graedel, 1996; Verhoef et al., 2004) and circular economy (Yuan et al., 2006) are also pertinent for metals, however circular economy literature pays limited attention to stocks and global carrying capacity.

The development of a notion of responsible minerals and energy consistent with a sustainable future, requires not only an explicit acknowledgement of the minerals-energy nexus, but also of the services required in a sustainable society and the quantities of minerals and energy required to underpin these services. Non-metallic substitutes for minerals may become more prevalent in future and responsible minerals would then need to extend to justifying why metals (over the non-metal alternative) are most appropriate for particular end uses.

Key characteristics of responsible mineral chains should consider:

- *Mineral source*: responsible, transparent social and environmental practices for mining and refining from primary and secondary sources.
 - o Needing to be added to the current conceptualisation is an assessment of the scale of practices acceptable within the supply chain. For example, if all steel became 'responsible' would impacts still be considered sustainable and consistent with one planet living over the long term? And what are absolute impacts over time (not just per tonne of metal)?
 - o Mature chain-of-custody standards for secondary materials are currently lacking
- *Mineral/metal use and re-use*: rates of use are responsible given available stocks and competing uses; metals are used in products which can be long lasting, reused; collection and recycling channels are well functioning; minerals-energy nexus acknowledged as opportunity for innovation.
- *Multiple perspectives*: explicit consideration of multiple stakeholder perspectives over the long term are needed: industry, government, citizens
- *Minerals-energy nexus*: the nexus between the minerals and energy sectors are increasingly linked and the opportunities (e.g. for renewable energy linked to mineral production) and constraints this brings should be identified.

Having identified the need to consider the mineral-energy nexus, both in long term futures and as part of responsible mineral production, the following section will draw-out the societal and policy considerations for responsible minerals using examples of alternative countries and commodity chains.

4 Views at minerals-energy nexus: contrasting perspectives from producing and consuming countries on responsibility, social licence and futures

The role of the case studies in this section is to ground the theoretical discussions present in earlier sections of the paper in real-world examples. Thus are illustrated areas where futures perspectives of the mineral-energy nexus and of 'responsible' vary between cases and between producing and consuming countries.

4.1 Rationale for case study selection at the minerals energy nexus

The interaction between minerals and energy futures is becoming more highly intertwined with the consideration of climate change mitigation, clean energy technologies (Memary et al., 2011) and economic vulnerability to loss of supply. Three key examples are:

- Uranium production and the nuclear power industry;
- Critical metals for energy technologies; and,
- Coal for steel production and future potential for electric arc furnaces to recycle steel powered by renewable energy

and each is explored from the perspectives of Australia (producer), Japan (consumer) and Switzerland (consumer).

Mineral inputs into energy systems, particularly functional materials, enable energy systems to operate efficiently. In the case of Uranium, a fuel mineral, the economic reserves of the mineral dictate the future potential for the continued expansion of this form of low-carbon power. However, the embodied energy and emissions of the supply chain are being examined, with the underlying low-carbon credentials being called into question (Sovacool, 2008).

For critical metals – such as rare earths – utilised in permanent magnets for wind turbines or in high efficiency electronic devices, the limitations of supply are also a clear threat or limitation to the ultimate ability to cover a large proportion of the global market (Hoenderdaal et al., 2013). Price and political issues are important factors at play in this field.

Finally, coal and steel – an example of an integrated mineral cycle – is globally a highly significant greenhouse gas emissions source, with the steel industry producing around 25% of global industrial emissions in 2009 (Allwood et al., 2010). Despite some potential for reducing emissions through the use of charcoal (Norgate et al., 2012), ultimately the greatest potential may lie in utilising renewable energy and electric arc furnaces with a large recycled scrap content and the remainder direct-reduced iron. In this situation the potential for utilising a greater percentage of low-carbon

electricity is possible, although it relies heavily on a highly effective and efficient collection system for scrap, and there are limits to its expansion.

Following an overview of each case study's context, the cases of uranium-nuclear, coal-steel and rare earths-renewables are described in turn, with particular reference to relevant country perspectives therein. In addition, the hitherto explored themes in the paper, viz. future focus, social licence, responsible minerals and the minerals-energy nexus are described for each case.

4.2 Overview of country contexts

4.2.1 Australia

Australia is a large producer of minerals, but is only a relatively small consumer, with most of the minerals being exported as ore or concentrate. Among the products it produces that cross the minerals-energy nexus are uranium, coal and rare earths, of which the uranium is overwhelmingly for export, with only a very small experimental nuclear reactor for medical and material purposes operating domestically. The dominant energy source for power is currently coal. Coal is used domestically for power generation and in the limited steel production occurring locally, but a large proportion is exported. The Rare Earths are exported as concentrate.

4.2.2 Japan

Being a consuming country, with few conventional mineral or energy resources (USGS, 2013), Japan has largely focused on recycling minerals, purchasing or financially controlling energy resources, and the development of technology to improve efficiency of energy usage. Japan imports uranium, coal and rare earths and utilises them to produce electricity, steel and energy / electronic equipment such as magnets for electric motors used in wind turbines and electric vehicles.

4.2.3 Switzerland

Like Japan, Switzerland is a mineral consuming country, and domestic material consumption (national natural resource use) has slowly increased from a low in 1999 of approximately 80 million tonnes/year, to around 100 million tonnes/year in 2011 (Federal Statistical Office (FSO), 2011). Metal processing in Switzerland is restricted to secondary aluminium, lead, and steel, and these activities depended on imported raw materials or scrap (Federal Statistical Office (FSO), 2011; Giljum et al., 2010; Newman, 2013; OECD, 2008).

4.3 Uranium-nuclear

Given that that the majority of mined uranium is used in nuclear power, uranium mining outlooks are closely connected to energy outlooks, that is, longer-term than for other minerals. For example,

the Economic Outlook of the Australian Uranium Industry (Australian Uranium Association, 2013), cites 2035 projections from the IEA with respect to future demand for nuclear power. The fact that most uranium is used for power generation also means the minerals-energy nexus is implicitly acknowledged. However, the complexity of the nexus is relatively straightforward as the competing applications (e.g. military applications, for the manufacture of radioisotopes for medical applications) use far less quantity of product than for electricity generation.

Australia is the third largest producer of Uranium and holds 31% of known recoverable reserves globally (WNA, 2013). However, it does not utilise uranium domestically except for research and medical purposes in a single experimental reactor. Nuclear power has not been considered in the power mix for many decades due to the abundance of cheap coal and strong social opposition to nuclear power. Uranium mining's social licence is also contested and there has also been significant opposition to the expansion of uranium mining. There is currently a national limitation on the number of mines in operation, some states ban exploration (Victoria), whilst New South Wales has recently allowed exploration and Queensland has lifted bans on uranium mining.

The concept of "responsibility" from the perspective of Australia as a producing country is mostly represented by the restrictions and requirements for environment, health and safety at mine sites, and the strict limitations on who the product may be sold to in line with the Nuclear non-proliferation treaty (although sales have been approved to non-signatory India).

Japan does not produce uranium but utilises nuclear power – although this may change in the future due to the impacts of the Fukushima nuclear accident (McLellan et al., 2013). In the case of the nuclear power industry, Japan's future forecasts included three particularly interesting elements:

- nuclear power is considered as environmentally friendly due to the non-generation of greenhouse gases at the site of production;
- nuclear fuel recycling is assumed to be achieved domestically with final storage of the fuel in a permanent facility;
- nuclear power plant and storage facility safety is assumed to be paramount and achievable.

In the case of nuclear power, futures are all assumed to involve extensive fuel recycling and eventual permanent storage of waste. Fuel recycling is yet to live up to its promise domestically, and no site has yet been found to take the radioactive waste. With the ongoing radiation leaking from the Fukushima plant, there has been a significant weakening in the justification and consequently social licence for of key elements of nuclear power futures.

Regarding the concept of “responsibility”, the key aspects promoted by both government and industry are safety, energy security, economic benefit and environmental credentials. Safety assumptions have been called into question due to the Fukushima accident, which currently has most of the nuclear power plants closed and awaiting advice as to whether they can reopen. Energy security is assumed to be increased by nuclear power due to the lower requirement for fuel imports - when Japan’s energy mix includes nuclear power as a “domestic” energy source, the level of import dependence drops to 80% when all plants are operating, as compared with the 96% if this assumption is not included (IEA, 2010). The environmental benefits of nuclear power are considered as reduced greenhouse gases during operation and localised pollutants when compared with thermal power stations. The potential for dramatic release of radiation (such as in an accident) or the ongoing thermal pollution to the oceans as heat is drawn off in cooling water is not typically discussed. Moreover, the supply chain release of GHG emissions and other pollutants is considered as not within the sphere of influence of the electricity generating companies.

Switzerland produces no uranium. Swiss private industry was involved in uranium mining in the western US between 1983 and 1995 (OECD/IAEA, 2008), and Glencore Xstrata (a Swiss multinational mining company) was unsuccessful in its bid for the Australian Western Mining company, and control of the Olympic Dam mine (copper, uranium, gold, and silver), in 2005 (currently this mine is operated by BHP Billiton). This highlights an interesting dimension regarding social licence, where the Swiss location of Glencore Xstrata headquarters could influence the social licence of operations in other countries.

Currently Switzerland has five operating nuclear power plants owned and operated by Cantonal energy suppliers. Each station manages its own supply of fuel, either importing ready-to-use nuclear fuel, or sourcing natural uranium or enriched uranium and contracting third-party organisations (General Electric or Westinghouse) to produce fuel rods (OECD/IEA, 2012).

Since 2006 the Swiss government has enforced a ten year moratorium on the export of spent fuel assemblies for reprocessing, choosing instead to store burned fuel (OECD/IAEA, 2008). This measure was taken as reprocessing of burned fuel became a politically sensitive topic due in part to the process of blending old fuels with enriched uranium, and because the environmental credentials of the supply chain (burned fuel was exported to Russia for reprocessing) could not be guaranteed (Whitwill, 2013). Because Switzerland’s nuclear plant operators have the responsibility to manage waste themselves, the moratorium on reprocessing has forced these government organisations to explore waste management options (storage at site of power generation, or transport to a storage facility in Switzerland), which may also be environmentally and economically questionable. In

contrast to burning coal which generates carbon dioxide emissions which readily traverse country borders, the key environmental challenge of nuclear technology is the management of solid waste, which in the Swiss case occurs within the country using the uranium.

Following the nuclear accident in Fukushima in 2011 (in which radiation leaking into the ocean also readily traversed country borders), Switzerland has committed to phasing out its five plants as they reach the end of their safe operational lifetimes. Given that these plants filled a significant proportion of Switzerland's electricity requirements, and have kept Switzerland's per capita CO₂ emissions relatively low in relation to international industrialised levels, there is concern that the replacement for the base-load power supplied by nuclear energy could increase the nation's CO₂ budget. However, the country's energy strategy to 2050 advocates for a significant rise in the role of renewables (particularly hydro power), for significant increases in consumer energy efficiency, and capped CO₂ budgets per capita that are aimed at offsetting this concern (Swiss Federal Council, 2011).

Overall, uranium is tightly regulated and well tracked at each stage of its life cycle. This could make it an interesting case to explore new approaches to 'responsible' mineral management such as Australia leasing uranium (as has been proposed for lithium by (Prior et al., 2013b)) to Switzerland, Japan or other countries and then being paid to taking back the solid waste. Whilst the siting of long term uranium storage facilities in Australia has been identified as an economic opportunity (Krieg, 2013), it faces considerable public opposition.

4.4 Coal-Steel

The coal-steel example offers an example of a mineral-energy nexus with more nuance and complexity and uncertain long-term future. Firstly whilst brown coal is primarily burned for energy generation, black coal is used for electricity generation and as a reductant (coke) for steel making in blast furnaces and as a fuel in cement making, amongst other uses. Furthermore, steelmaking can also occur via an electric arc furnace (particularly for recycled steel) which in future could be powered by burning coal or by renewable or nuclear energy.

Australia is the world's second largest exporter of coal and the fourth largest producer (WCA, 2012). Long term projections (beyond 2100) of coal production in Australia have been undertaken (Mohr et al., 2011) and global coal production is expected to peak in ten years. Domestically, coal is utilised in electricity generation and for modest steel production. Australia is also the second largest producer of iron ore, and one of the top two exporters (USGS, 2013). With regards to sustainability, both coal and steel producers are making attempts to improve the GHG emissions from extraction through to

utilisation, by investing into research for new technologies. However, coal and steel producers are necessarily restricted in their ability to achieve reductions in GHG emissions as coal utilisation (without carbon capture and storage (CCS)) is one of the largest contributors to global GHG emissions. The social licence of coal in Australia varies locally from mine to mine and becomes contentious where new mines are proposed on prime farming land. Moves for institutional investors (including universities) to divest from coal will also affect its future. The long term future of steel production in Australia is not as optimistic as projections of iron ore exports to feed steel production in China which have risen rapidly in the last ten years, although crude steel demand in China itself is expected to peak 2013-2015 and then remain high for seven to ten years (Wang, 2013).

Views of “responsibility” around coal and steel are therefore conflicted – from an immediate economic and employment perspective, coal and steel production should be maintained, whereas from a longer term global and local environmental perspective it would be more responsible to phase out production of thermal coal due to greenhouse gas emissions and local pollution from dust and fine particle emissions which cause health problems. The steel industry cannot currently operate without metallurgical coal or coke, hence a total reduction of coal production is not viable. The use of coal in steel-making can be argued to provide important development outcomes for emerging economies and thus is arguably consistent with a “responsible” approach. Biomass alternatives for coking of iron ore have been investigated and found to deliver environmental and social benefits (Norgate et al., 2012; Weldegiorgis and Franks, 2012). Moreover, the majority of iron ore and coal are exported, producing some local economic benefit, some international economic benefit for foreign shareholders while the majority of the environmental impacts are realised offshore.

The development of “Responsible Steel” in Australia is an example of supply chain responsibility, involving miners, manufacturers and recyclers (Benn et al., 2014). One of Responsible Steel’s first activities was undertaking a steel chain footprint, identifying the high embodied energy in Australian steel. This is one acknowledgement of the mineral-energy nexus, but does not fully capture vulnerability of the nexus if the dynamics for one component were to change. For example, if institutional investors avoid coal, this will affect steel production in blast furnaces. If steel producers move to electric arc furnaces, this will affect the market for coal. This highlights the importance of connecting foresight and longer term scenarios, including normative scenarios with today’s responsible practices and a transition towards tomorrow’s responsible practices.

Japan is the second largest producer of steel globally (behind China) (USGS, 2013). Japan has some domestic reserves of coal, but these are relatively uneconomic under current circumstances (despite the best efforts to keep the coal industry alive through subsidies (Surrey, 1974)), therefore it

currently imports both coal and iron ore in order to produce steel. It also imports some coal for thermal power stations, whose social licence has increased relative to nuclear following the Fukushima accident.

As an industry, iron and steel production accounts for around 9% of global GHG emissions from energy and industry (Allwood et al., 2010). Japanese steel production is relatively low-emitting by world standards (McLellan et al., 2012), which is mainly due to the efficiency of the plants, the mix of technology (electric arc furnaces versus blown oxygen furnaces), the use of by-product gas and low-emitting electricity in the process.

In conjunction with attempts to reduce GHG emissions, the approach to “responsibility” in the steel industry in Japan is closely related to recycling and the circular economy. Product design for durability and recyclability, and education to increase recycling are strong themes (JISF, 2013; NMI, 2008) as are longer term studies on stocks and flows of steel.

In Switzerland, there is an active steel industry (Newman, 2013), and scrap steel is a valuable resource in a mineral-poor country aiming to reduce input and output flows of minerals and metals (Federal Statistical Office (FSO), 2010). In the first quarter of 2012 Switzerland imported a total of ~2.5 Mt of iron and steel, of which ~13% was scrap steel and by-products of the manufacture of iron and steel products collected and imported from a global network of traders.

Like Japan, Switzerland’s has a strong recycling focus, with domestic material consumption a growing policy issue in the country that is driving consumption efficiency, recycling and material recovery practices. The use of high-efficiency Electric Arc Furnaces to convert steel scrap into high quality steel has kept CO₂ emissions from the industry relatively low (also because electricity is sourced primarily from hydro and nuclear power currently). The increased role which recycling will come to play in China may influence technology trajectories globally of an industry which has been mature for several decades.

4.5 Rare Earths-Renewable Energy

Rare earths have a number of key uses in electronics and renewable energy technologies – such as the permanent magnets in wind turbine generators or phosphors in high efficiency LEDs.

Australia is one of the four largest producers of rare earth oxide concentrates (USGS, 2013), but all of the refining and further separation of individual rare earth elements occurs offshore. China is the overwhelming majority producer of rare earths, and has recently been restricting exports and

production – ostensibly due to environmental concerns (Chen, 2011). With regards to “responsibility”, producers of rare earths tout the benefits of the end use technologies for moving towards a green economy which is what makes the mineral-energy nexus here interesting. At the same time, the concerns over environmental and health impacts of mining and processing (with radiation in tailings and processing, and other toxic waste storage leading the list of concerns) have caused disruption to production in China and the United States, as well as jeopardising the start-up of the Lynas Corporation plant in Malaysia (Ali, 2014). Moreover, there are arguments that the difficulty in obtaining regulatory approval for rare earths processing plants in developed countries is driving the location of these plants in developing countries – which is potentially a poor indicator of “responsibility”. The social licence of renewable technologies themselves, such as wind farms, has also been compromised by distributional justice (sharing of costs and benefits in communities) and procedural justice (Hall et al., 2013).

The use of these magnets in wind turbines (approximately 0.65-1 tonne per MW turbine capacity) has been of particular interest in light of China’s moves to limit exports (Bradshaw and Hamacher, 2012; Hoenderdaal et al., 2013). Japan is one of the largest producers of LEDs and rare earth magnets, and has been impacted heavily by the Chinese restrictions, leading to investment in projects outside of China.

The concept of “responsibility” from the perspective of producers of efficient electronics and low-carbon energy technologies focuses on the benefit to GHG reduction. Japan is also investigating recycling of rare earths (Ishii et al., 2013) and considering deep ocean mining of rare earth deposits as a means of securing supply (Government of Japan, 2013), although the implications – both with regards to stakeholder consultation and environmental impacts – are unclear.

The concept of ‘responsibility’ in the context of rare earth elements (REE) in Switzerland is somewhat addressed in sustainable investment funds and practices. For example, several private sector investment firms have established a ‘REE Fund’ recognising the importance of rare earths in modern technologies and especially green energy technologies and energy storage.

The possibility to recycle REE from municipal solid waste as a form of ‘urban mining’ has been explored in Switzerland (Morf et al., 2012). However, given the low number of facilities using rare earths in production, efforts in this regard have been minor compared to those made by Japan.

4.6 Case study comparison

Consuming countries like Japan and Switzerland have fundamentally different approaches to, and attitudes towards material consumption, import dependence and recycling, than producing

countries like Australia. The two consuming countries examined here tended also to have more specialised secondary production (and processing) facilities. Recycling and recovery practices were seen to support secondary industry by providing source material for future processing. In Japan, the practice of Extended Producer Responsibility ensures that products containing valuable materials and metals can be recovered by those industries most in need of the materials., and this is also part of its long-term resource strategy for a Sound Material Cycle Society.

Switzerland's small steel industry has established a global network of scrap steel and iron collectors, which is fundamental for the industry's operation. By contrast, in the last half decade in Australia, strong base metal prices have driven a concentration on primary production, to the detriment of the local export industry, including secondary production facilities (Corden, 2012).

In the case of uranium-nuclear, nuclear energy was seen as responsible in Japan and Switzerland before Fukushima, although not in Australia (despite it being a significant uranium exporter). For rare earths, many concerns regarding social licence and environmental impact are downplayed due to their central use in renewable energy technologies. The long-established coal-steel nexus has huge global impacts and has been the focus of more efficient technology development, both to improve efficiency and to use (renewable) electricity instead of coal.

Table 6 provides a summary of the case studies and their links to the themes explored in this paper and identifies key issues.

Table 6: Summary of case studies

	Rare earths-renewables	Coal-steel / Electric-arc-renewable-recycling	Uranium-nuclear	Comparison
Foresight / time horizon	Rare earths: short and long term supply constraints have been focus Renewables: long term view of increased role in energy supply	Coal projections to 2100, also steel.	The uranium-nuclear energy pair are tightly linked with energy being a key use of uranium outside military. Positioned as part of long term future, in part to re-justify social licence.	Rare earths-renewables a growing industry. Coal-steel mature, slower evolution and projected coal decline. Uranium-nuclear mature but stalled.
Social licence	Social licence issues both for rare earth mining, processing and also renewable technologies such as wind farms	Flagging social licence of coal is not directly undermining social licence of steel	Contested social licence issues from uranium mining to nuclear power	Huge variation, by commodity and location.
Responsible minerals/energy	Little explicit focus on responsible	Responsible steel is an example of	Responsible framed as mitigating	Notion of 'responsible' most

	mineral chains for rare earths	working to develop a responsible supply chain certification for green product differentiation	climate change; challenged by nuclear accidents. Most tracked at every part of supply chain.	developed for steel. However uranium most traced along supply chain, yet social licence weakest.
Minerals-energy nexus	Vulnerability of renewables to rare earths supply is acknowledged. There is less discussion of renewable powered rare earth mines.	Partially, framed as steel having high embodied energy. This is a complex nexus due to the potential technology disruptions to a mature industry	The minerals energy nexus is strong and relatively simple for uranium-nuclear (except for the complexities of polymetallic mines supplying uranium)	Variable and unsystematic – future research could focus on developing a minerals-energy nexus typology to better characterize links.
Range of country perspectives	Malaysia (site of rare earths processing plant) was not an explicit focus in this paper, but perspective is relevant. In Switzerland, Japan and Australia rare earths are considered a key part of a better future.	Japan is second largest producer of steel after China and Australia is huge exporter of iron ore and coal.	Australia holds unusual position of exporting uranium whilst opposing nuclear power. Fukushima has changed role of nuclear in Japan and led to phase out in Switzerland.	Perspective of ‘producing’ or ‘consuming’ country not able to be generalized, context is country and commodity specific. Importance of comparison is in illustrating range of positions taken.
Key issues/trends	Technology for recycling of rare earths and design-for-recycling in renewable energy	Possibility of renewable energy-powered electric arc furnaces displacing coal in longer term	Challenge of energy security without uranium for selected countries	Articulating ‘responsible’ mineral and energy platforms both today and in the long term future

This section shows the breadth of complexity which exists at the minerals-energy nexus from multiple perspectives and which needs to be included in an expanded notion of ‘responsible’.

5 Concluding discussion

This discussion is structured around the research questions for the four themes of this paper.

5.1 Is the minerals sector adopting a longer-term view?

The future-in-view and supply-demand projections for minerals are generally seen to be shorter than for energy, namely a decade or less, rather than multiple decades. This information constraint is problematic for understanding likely mineral and energy futures, let alone developing desirable futures consistent with sustainable development. In response, future supply-demand projections which extend 30-50 years should be developed for minerals in the same way as for energy.

Production or supply-side estimates and reserve limitations could be developed readily quickly, given that organisations such as the USGS already compile such data (although admittedly with variable levels of accuracy). The demand for many minerals is not as clear-cut as the demand for energy, due the various consumer products in which they may be incorporated however, with the recent focus on critical minerals, efforts are being expanded in this area. Identifying a suitable organisation for compiling such estimates is not straightforward, this could be a task for the International Resource Panel (UNEP) as the International Council on Mining and Metals does not routinely compile data as the International Energy Agency does.

The longer term view should also pay more attention to articulating desirable futures and the role and structure of minerals extraction technologies, resource use and metals reuse in sustainable futures, taking account of the mineral energy nexus. This can help strengthen social licence to operate in the short term, whilst demonstrating the useful role of metals (including relative to non-metals) in delivering the services required by futures societies.

5.2 What are the risks of overlooking the mineral-energy nexus?

Overlooking the mineral-energy nexus is increasingly problematic. As the world faces increasing resource constraints, vulnerabilities arising from inter-dependencies become more important. Considering the nexus, also expands the frame in which to pursue abundant opportunity, for example the ability of producing nations like Australia to, for example, export virtual sunshine if mines and refineries were powered by solar energy. Vitally important with regards to future research and development in this area is understanding and creating more normative, quantitative future scenarios that consider the development of society along preferable as well as likely transition paths. There are also risks to social licence, for example, the flagging social licence of coal is not yet affecting the social licence or production infrastructure of steel, but taking a long term view at the nexus brings focus to this issue. A further point to note is how quickly a change in the social licence of nuclear power can affect the future and social licence of the uranium mining.

5.3 As industry emphasises social licence and responsible minerals over sustainability, what is left out, what should be added?

Social licence is currently considered key to the future of mineral mining, processing, consumption and recycling from an industry perspective, and can also have a strong effect on the favourability and siting of energy technologies or facilities. The dominant experience with social licence for mining companies has been at the mining and processing stages. Recycling is recognised as an important linkage in maintaining supply, reducing waste and ultimately closing the material cycle, however

recycling can be executed well or poorly. The informal recycling sector in Asia poses a problem not only to the health and wellbeing of workers and their environment where this takes place, but also to producers of electronic goods.

As social licence moves from being site based, towards a technology class and indeed along the supply chain, responsible supply chain initiatives must tackle this. Whilst chain of custody standards have begun to emerge as a representation of responsible practice for primary miners, no such standards exist for recycled goods. In the energy sector, the consideration of responsibility and social licence is already largely at the scale of technology classes or supply chains. Focus is placed on the ability of a technology mix to supply society with energy that is both economically affordable and environmentally beneficial. At the minerals-energy nexus a potential collision of time and geographical scales of consideration has implications for the ability of stakeholders to adequately engage.

The rise of a discourse of 'responsible mining and minerals' in place of sustainability is occurring. What gets brought to the foreground and left behind in this transition is important. A key aim of this paper was to identify that this occurrence needs further scrutiny by industry, researchers, citizens and governments. Currently, responsible mining emphasises social practices along the supply chain, but not necessarily the use of mining revenues or taxation for sustainable development. Nor is the (un)sustainability of the rate at which responsible mining is occurring, nor the continuous growth paradigm being questioned. What is promising is the development and wider diffusion of traceable chain-of-custody schemes, albeit somewhat heterogeneous. As these develop, the norms, expectations and social licence relevant to stakeholders (including investors over the long term) in producing and consuming countries will need to be better understood. Such issues also cross-over readily into the energy sector, where developing countries must weigh-up the use of domestic fuels locally or as a source of export income. Often this leads to the export of higher price, but more environmentally benign fuels, while local generators utilise cheaper but more polluting sources. Responsible mineral and energy futures will necessarily put an increased focus on design, both of products needed to deliver the services required in a more resource-efficient future, but also of the systems which underpin how our energy and resources are used and collected in our cities.

5.4 Learning from country views at the mineral-energy nexus, what should be included in a research agenda for an expanded notion of ‘responsible’ mineral futures?

For countries currently consuming primary resources (e.g. Japan, Switzerland), mastering recycling technology (such as for rare earths) would enable them to control urban mines of the future. Considering the overall energy utilised in such processes is also important, as it is common for minor materials and alloy recycling to utilise almost as much energy as is required to produce from primary ores.

For producing countries like Australia, there has been a tendency not to have a national resource and energy strategy (unlike Japan which is more dependent on imports). This represents a short-sighted view of the global situation, but in light of the apparent short-term abundance, their focus may be more appropriately viewed in connection with environmental and social benefits that may arise from a co-ordinated national strategy.

A key theme emerging from the case studies views at the nexus is complexity and interdependency. In particular, these themes must be included, together with a longer-term orientation in an expanded notion of responsible.

Whilst this paper only explored selected cases at the nexus for producing and consuming countries, further research could usefully focus on the role of innovation in responsible supply chains and on the perspectives of other countries. These may contrast producing-developing countries (such as Brazil), with producing-developed (such as Canada) and producing-consuming (such as China). These latter points could be extended to involve an examination of equity across the nexus of minerals-energy and development.

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